BIM Technology for the Infrastructure Projects

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Abstract
Building Information Modelling (BIM) has become increasingly important in the construction industry and is used to plan, design, construct, and maintain buildings and infrastructure. The literature review analyzes BIM implementation in transportation infrastructure projects, focusing on Industry Foundation Classes (IFC). It analyzes twelve infrastructure BIM implementation case studies. The review examines the barriers and challenges of BIM implementation in transportation infrastructure projects and highlights the contributions of BIM. It begins by reviewing existing literature on BIM implementation. BIM possesses the ability to provide major benefits to the transportation sector, including project coordination, improved visualization and communication, minimized errors and rework, and strengthened project efficiency and sustainability. However, there exist various barriers and challenges that impede its extensive implementation.

Keywords: *Infrastructures, Building Information Modelling, Industry Foundation Classes*

1. INTRODUCTION
Digital twin technology gathers and transmits real-time data from physical assets, modeling the physical asset virtually. The deployment of DT technology in the building sector has seen changes recently [1]. Digital twins give the construction industry some hope as it has slow technological innovation, knowing that it considerably impactsocial and economic growth [2]. A unique technique for virtual real integration and tunnel digital twin creation increases the effectiveness of tunnel management and operations, and a tunnel in China was chosen to test the method's efficacy [3]. Besides traditional methods that increase project risks and delays, costs, and safety, a 4D BIM model and safety measures were established by technicians at the M4 metro line site to improve tunnel management and are appropriate for comparable works [4]. Convergent technology combines BIM, AR, BCT and DTs for effective research and invention in the building sector [5]. DTs enable optimizing, monitoring, simulating, anticipating, diagnosing, and managing physical processes, opening up new economic opportunities and decision-support frameworks [6].

BIM, which enables collaborative project design, construction, and operation, is a digital representation of a building's structural and functional characteristics. The framework can offer effective and automated decision analysis to help with tunnel operation and maintenance [7]. As a result, predictive maintenance, early problem detection, and improved safety are all made possible by the real-time monitoring and analysis of performance while in operation. A platform for information management and ensuring data integrity is known as a framework, and it is also considered a benefit [8]. Although the benefits are desirable, many challenges still exist in implementing BIM in infrastructure projects. As a result, a comprehensive analysis of the available literature review on BIM in infrastructure and investigation of the current state of these technologies will provide areas that need more research and suggest future research developments. The development of BIM for infrastructure projects is summarized in this paper. First, an overview of BIM in infrastructure projects is presented. Then, the implementation of BIM challenges in projects is summarized.

2. AN OVERVIEW OF BUILDING INFORMATION MODELLING IN INFRASTRUCTURES

The design, construction, operation, and maintenance of infrastructure projects are being transformed by the powerful digital technology known as BIM. BIM is a collaborative process that combines multidisciplinary data and information into a virtual model, providing project stakeholders with a shared platform to view, simulate, and manage an infrastructure project's entire lifecycle. From bridges and highways to water and wastewater systems, BIM is being widely adopted in the infrastructure industry to improve project outcomes and enhance sustainability. BIM enables a more efficient and integrated approach to infrastructure project management, facilitating better communication, coordination, and collaboration among project teams. Stakeholders can visualize, evaluate, and optimize 3D projects using BIM, which leads to improved decision-making, fewer mistakes, and better results in terms of cost, time, quality, and safety. Additionally, it helps in the upkeep and operation of infrastructure assets. BIM can be used to capture as-built data, generate facility management data, and support asset management throughout the lifecycle of infrastructure projects. This enables comprehensive maintenance, asset performance and facility management, enabling more efficient and effective operation and maintenance of facilities [9]. However, implementing BIM in infrastructure projects also presents challenges, such as skilled personnel, interoperability among different BIM tools and technologies, data management, and cultural and organizational changes. Nevertheless, the potential benefits of BIM in infrastructure projects are substantial, including improved project outcomes, enhanced sustainability, increased collaboration, and reduced lifecycle costs [10]. Challenges and knowledge gaps when applying project management expertise to create decision support system models, along with their identification [11].

The pultrusion process is more precise than alternative methods of manufacturing fiber-reinforced polymer poles, but it is also more expensive [12]. On the opposite, conic samples showed the lowest value of (E) and a fair value of (G) because the (L/r) values ranged between 9 and 32, which is much less than 170; accordingly, the shear deformation contributions were significant [13] [14]. When used in conjunction with solid slabs for short spans and ribbed slabs for medium and long spans, the dual system is the most appropriate system for medium and high-rise buildings [15]. Decision support systems and value engineering are rich fields that have been extensively studied by researchers from various angles and techniques [16]. Four projects verified the DSS adjusted for Egypt in 2019 [17]. To choose the best structural system for a multi-story building in Egypt, perform analytical investigations based on key performance indicators for client satisfaction [18]. A simple computer model is designed for recommending the optimal composite flooring system of a multistory building, during the preliminary design stage. The value engineering (VE) team to achieve the VE goals mentioned above can use the model [19]. However, in the context of transportation infrastructure, the adoption and implementation of BIM have been slower. Although efforts are being made by industry and academia to adopt BIM for non-building civil infrastructure, there has not been a comprehensive review specifically focused on transportation infrastructure. Previous literature reviews have covered civil infrastructure facilities, existing buildings, and data management applications such as BIM. Transportation infrastructures lags behind the industries in implementing BIM and DTs technologies [20] - [21]. Five key areas of infrastructure were divided into transportation, energy, utility infrastructure, recreational facilities, and environment [22].

2.1 BIM for transportation infrastructure

The fundamental physical and organizational systems and facilities crucial for a society's functioning and operation are referred to as infrastructure. This infrastructure includes public transportation systems, bridges, tunnels, highways, and railroads [23].

2.1.1. Bridges: Using different software tools to create and implement BIM content for various projects, it's important to emphasize that BIM is a methodology for information management, not tied to any specific software. Hence, seamless data exchange between different BIM systems is crucial [24]. BIM is a new technology to improve collaboration and minimize composite cost during the life-cycle of a bridge. Zou et al. [25] presented a model-based BIM framework for bridge engineering and gave an overview of the current workflow for delivering bridge projects. BIM and GIS are being used more and more by the bridge engineering industry to handle bridge projects in an automated, efficient, and thoughtful manner. The study looked at 90 journal articles and found difficulties in creating BIM and GIS standards, standardizing design modeling protocols, streamlining construction procedures, and investigating cost prediction techniques. Clarifying management department needs and exploring omnidirectional data-collecting methods for operations and maintenance should be the key goals of future development.

The conclusions can help bridge engineering professionals choose the best BIM/GIS technology for various stages of bridge projects, and they can also help with future research and development to enhance the use of BIM/GIS technology in bridge projects [26]. The new architecture for a BIM-based bridge data management system considers all facets of maintenance operations. Engineers can save time and money by modifying the system for different bridge types. Owners, designers, contractors, and maintenance managers are among the stakeholders who must describe the system's information needs. A single format is used for data sharing, and certain file types are designated for storing 3D model data, attributes, and archives. Design teams may quickly create 3D models using parametric modeling, starting with bridge parameters. The system also has an algorithm for adding damaged layers to a 3D model and automatically creates field inspection reports. The Main Management Module and the Inspection Module are the two components that make up the BMS [27]. In life cycle management, EBS coding may manage BIM modeling in addition to project- and network-level management. Creating and adopting EBS coding standard will significantly advance China's adoption and use of BIM technology [28]. BIM technology and sensor potential can be used in building management. Real-time monitoring and control of structures may be accomplished by measuring distance and connecting to the virtual BIM model. The suggested remedy requires minimal energy, and a solar panel connection is available for continuous monitoring. Future studies might consider actual bridge architecture and use sensors with greater resolution and range [29]. Framework has helped the BIM-based system enhance its management of inspection information. In the operational phase, it systematically links inspection records with BIM element models. Develop a DSS using MCDM techniques to select the best construction method among three alternatives - anchored post-tensioned, post-tensioned, and monolithic - based on criteria such as lateral stiffness, ductility, risk, maintainability, constructability, cost, and time [30].

Furthermore, the approach is centralizing all bridge BIM models for maintenance and inspection. With this concept, the present 2D-based form of information management is being overcome [31]. By viewing and tracking structures horizontally, 4D BrIM assists in locating problems, cutting down on delays, and improving project performance. Industrial applications that emphasize conflict detection, quantity calculation, and 3D visualization are the most widely used in India [32]. By managing all bridge data in a single model throughout the bridge life cycle and assigning fault information to specific model elements, BrIM has the potential to minimize the frequency of site visits by removing the need for data entry twice with the use of cloud computing [33] [34] [35].

2.1.2. Roads and Highways: IFC standards have been extensively defined for vertical structural components like columns and pillars, while work is currently being done on horizontal components like road infrastructure. Because of errors in data transfer and interoperability, BIM maturity in infrastructure is intermediate. Using Navisworks for thorough graphic visualization, evaluate master models across all disciplines and models, such as vertical and horizontal works [36]. Although I-BIM is not widely used in Europe, its advantages may be shown in upgrading an SS 245 road stretch. Modeling 3D digital topography, producing parametric models, and setting up horizontal and vertical alignments help stakeholders better perceive simulated environments and see possible design, building, or operational problems using I-BIM. Direct extrapolation from Civil-3D to STR Vision CPM is possible without the need for manual calculations thanks to a plugin for project costs evaluation [37]. BIM tools expand the number of possible solutions, shorten the design process, and enhance asset understanding. It promotes professional teamwork, reduces waste, and allows for well-informed design decisions. For the best infrastructure asset management in the future, plant design and 6D and 7D BIM models will be integrated [38]. Traditional approaches still contribute to plans for infrastructure renovation, but BIM provides advances and advantages over them. BIM presents a complementary nature by highlighting flaws and making complex issues simpler. For sustained integration, it is advised to put in place a legal incentive system and fund internal BIM training [39]. Despite its relatively slow acceptance in Malaysia, the potential of BIM technology to revolutionize the transportation business was proposed. Workflow that is not collaborative, design modifications, and design disagreements are difficulties. However, high prices, resource commitment, and scant government assistance hamper the implementation of BIM. A framework provided for future investigations into the industry's strategic implementation plans for BIM [40]. Four highway construction projects were studied to validate the DSS. It aligned with the best decision in 3 out of 4 cases. Results showed fully sloped embankments are ideal up to a certain cost, beyond which fully retained embankments are better [41]. With integration into the multi-scale location framework necessary for national digital twins, BIM and GIS are important sources for this data. GeoBIM contributes to this process; however, system interoperability and awareness issues need to be resolved. GeoBIM has a long-term advantage by combining already existing data from the BIM and GEO domains for operational information management. Recording potential data loss will increase awareness, emphasize the value of data integration, and make it easier for Asset Managers and the construction sector to work together [42]. A DSS was used to predict the most effective soft clay improvement method for highway construction in northern Egypt. In three out of four scenarios tested, the DSS accurately predicted the best method [43]. Throughout a project's lifespan, BIM is a valuable technique, thus project managers must provide guidance on its implementation and evolving technology. While BIM Design Applications and simulations passively affect V.O., Contract Parties, consultants, and other factors have positive benefits [44].

2.1.3. Railways: The I-BIM technique combines model management software like Navisworks Manage with three-dimensional modeling programs like Civil 3D and Revit, is an acceptable design method. However, there are interoperability gaps that result in the separation of management operations from the modelling process, which slows down output. This may serve as the foundation for further artificial intelligence applications [45]. Railway projects must overcome technical, interpersonal, and procedural difficulties while implementing BIM. Handling big files, the absence of standardized data sharing, and poor design software are examples of technical difficulties. Engineers need to maintain their own drive while navigating the switch from 2D to 3D design. Three out of five businesses report that it takes a long time to generate 3D BIM models, which is cause for concern. Combining models into various software and ambiguous Employer Information Requirements causes dissatisfaction. BIM provides advantages for railway projects; however, how it is applied depends on the nature, scope, and stage of the project [46].

New AI model uses Ant Colony Optimization to optimize overhead power transmitting lines routing. The model generates random and valid routes, estimates their cost and uses ACO technique to find the best route. Implemented as a prototype using VBA codes, the model's functionality was validated in three virtual case studies and assessed in a real-world case study. Results show that the optimized route's total cost is approximately 75% less than that of the original route [47]. BIM integration into rail projects is still in its infancy and needs government approval, tools, and technological development. Cost management, decision assistance, preventing design mistakes, resolving interface issues, vision planning, prefabrication, maintenance and facility management are a few benefits of incorporating BIM [48]. [49] developed digital data, legal requirements, and federated virtual models to combine BIM and GIS technology for regional railway rehabilitation and management. The technique encourages decision-making and cooperation among several stages. Lee et al. and Gao et al. suggest using BIM for functional features, management, and carbon dioxide generation estimations in information modeling for train bridges based on Industry Foundation Classes (IFC). [50] [51]. The system stores management and geometric information independently, and the station owners chose several to use nD technology. If necessary, nD models for more stations can be created later. [52].

2.1.4. Tunnels: The implementation of BIM solutions in construction management was examined by Li et al., with an estimation of real-time mistake detection, time and money savings, and increased productivity. [53]. Due to the massive scale, lengthy investment, and potential of geological disaster, tunnel engineering encounters difficulties during construction regularly. A life-cycle theory approach and a benefit assessment model for implementing BIM technology increased comprehensive operation rates by 59.9% and project management efficiency by more than 90 points. [54]. A digital twin approach for smart safety assessment in tunnel construction combines BIM, Midas, and LSTM with IoT and intelligent sensor technologies to collect data. The technique facilitates real-time safety evaluation and condition prediction of construction elements while reducing effort and increasing efficiency. This clever safety management strategy improves construction and serves as a model for subsequent studies [8]. The integration of VR and BIM in highway tunnel safety and maintenance shows effective integration, recognizing interdependencies and complexity in training systems and enhancing training effectiveness. It offers an immersive perspective that enables emergency response workers to understand various disaster circumstances visually. As application scenarios are expanded and wireless sensing technologies are incorporated, future work will incorporate augmented reality (AR) and additional visualization tools [55]. This novel method raises the bar for quality and effectiveness by addressing structural stability and safety difficulties. BIM technology is essential for green building and lean manufacturing since it decreases costs, project time, and energy usage [56]. application research and parametric tunnel modeling based on BIM are used to gather information and specify the parameters for an algorithm [57]. Early BIM use in tunnel building and wise application of instruments like CDE enhance social and economic sustainability. This necessitates a modification to official processes.

A thorough sequence of interviews within BIM project teams is required to extract perceptions of social and economic sustainability in a corporate setting. To address social sustainability, interdisciplinary collaboration with social scientists is crucial [58].

3. USING IFC FOR INFRASTRUCTURE

BuildingSMART established the Infrastructure Room in 2010 as a hub for many worldwide groups adopting IFC for infrastructure to broaden their reach. More information about the projects' status may be obtained on the homepages of the buildingSMART International User Group and the bSI Infrastructure Room [59]. Roads, railways, bridges, tunnels, and utilities are several major IFC expansion projects that especially focus on transportation infrastructures. Some of these projects include:

3.1 IFC Alignment for Road Infrastructures (IFC-Road)

This project aims to develop a data model and exchange requirements for representing road infrastructure objects, properties, and relationships using the IFC standard. IFC-Road focuses on enabling the exchange of digital road design and construction information, such as alignment, cross-sections, and pavement materials, among software applications and stakeholders involved in road projects. The semantics of form objects in a three-dimensional model were captured by identifying and including the spatial and physical components of the road infrastructure in the IFC [60]. This work also exhibits the hierarchical aggregation of structural components used in the digital modeling of road infrastructure. J. Amann et al. [61] presented an inversion of control in the design of an alignment model standard. This approach could exchange functions to interpret these values in order to visualize or analyze curves.

3.2 IFC Alignment for Railway Infrastructures (IFC-Rail)

IFC-Rail focuses on developing a data model and exchange requirements for representing railway infrastructure information, which can be used for interoperability and coordination among railway design and construction software applications.

Gao et al. [62] presented a data model to facilitate railway data interchange across both platforms and fields. Semantic and geometric modeling are the two main components of this standard based on the IFC standard. Visual inspection of examples and a trial railway project in China have both proven its viability. Lee et al. [63] proposed information modeling and management methods of railroad bridges using the current version of IFC.

3.3 IFC Alignment for Bridge Infrastructures (IFC-Bridge)

A new modified IFC-BRIDGE is proposed by merging both French and Japanese product models [64]. IFC-Bridge is extended to allow parametric geometry representations by introducing a novel object-oriented data structure. Geometric constraints and mathematical expressions are applied to develop relationships between geometric elements and their dimensions [65]. The extended data schema is implemented and evaluated using a real-world application scenario in the civil engineering domain. Yang Ji et al. [66] conducted an object-oriented data model to record parametric design, including geometric and dimensional constraints, is described in detail and a potential extension is provided.

3.4 IFC Alignment for Tunnel Infrastructures (IFC-Tunnel)

Yabuki et al. [67] developed a conceptual model based on the standard IFC format, resulting in a product model called IFC-Shield Tunnel and applied it to an ongoing tunnel project in Tokyo. This model comprised tunnel members, components, geology, and layer organization. A tunnel information modeling framework was recently introduced to facilitate the management and simulations of mechanized tunneling via a tunnel boring machine [68]. By expanding IFC, IFC IFC Shield Tunnel was created [69] [70] [71] [72].

4. CHALLENGES FACED BY BIM ADOPTERS

Efficient data exchange relies on established standards such as Industry Foundation Classes (IFC) and LandXML, which provide a common data format for exchanging information among different software tools. Ensuring that data exchanged among different software tools accurately represents the infrastructure assets' semantics (such as properties, attributes, and relationships) and geometrics (such as geometry, spatial information, and topology). Achieving consistency and accuracy in data exchange can be challenging due to differences in data formats, standards, and definitions used by different software tools. Ensuring that data exchanged among different software tools retains its integrity, accuracy, and consistency to avoid potential data discrepancies or errors that could lead to misinterpretation or miscommunication among stakeholders [73]. Transportation infrastructures may have legacy data, such as as-built drawings, survey data, and asset information, that must be integrated into BIM models. These projects may fail without better software compatibility, overwhelmed by information requests. Interoperable data schema protocols can be used to exchange bridge information in the planning, design, detailing, fabrication, and construction phases [74]. Also, lack of standardized contractual languages and legal frameworks for BIM, including contract templates, model ownership, intellectual property rights, liability, and data ownership, can create uncertainty in legal and contractual matters [75] [76] [77]. Common barriers faced BIM adopters as lack of knowledge [78] [79] [80] [81], Lack of resources [82] [83] and Lack of standards [84] [85]. According to the widespread adoption of BIM by individuals, businesses, and government agencies, the implementation has gained significant popularity in the construction industry. As indicated in Table 1, BIM is used at many stages of the construction lifecycle, from planning and designing to building and maintaining various structures.

Table 1. BIM is being applied in Various Phases of the Construction Lifecycle, from Planning and Designing to Constructing and Maintaining Different Yypes of Buildings and Infrastructures

BIM Implementation Challenges	Lifecycle Stage	Reference
• Lack of standards, methods, and contractual languages for BIM. • Difficulties in integrating multiple disciplines into a single BIM model. • Accuracy, completeness, and consistency of design data. • Standardization of design libraries and templates.	Design	[86] [87] [88] [89] [90]
• Accurate quantity takeoff, cost estimation, scheduling, and procurement based on the BIM model. • Standardized methods for extracting data from the BIM model and integrating it into preconstruction processes. • Integration of BIM with other preconstruction tools, such as project management and procurement software.	Preconstruction	[91] [92] [93]
• Managing construction progress, on-site activities coordination, and real-time BIM model updates. • Effective communication and coordination among multiple stakeholders during construction. • Site data collection, accuracy, and consistency of as-built data. • Field data integration with the BIM model.	Construction	[86] [87] [89]
• Asset management, facility maintenance, and facility management using the BIM model. • Integration of the BIM model with facility management systems, maintenance schedules, and asset tracking systems. • Data accuracy, completeness, and consistency over the entire infrastructure lifecycle. • Standardized data formats and exchange protocols for data management.	Operation & Maintenance	[94] [95] [96] [91] [97] [98] [99]

However, despite its benefits, BIM implementation is not without its challenges and barriers. Table 2 shows the identification of the barriers and challenges that may appear during the process of the implementation of BIM through case studies. These case studies are analyzed to address these challenges, improve the implementation of BIM, and emphasize the contributions.

Table 2: Some Case Studies of Implementing BIM for New and Existing Construction

Case Study	Applications	Identified Challenges faced by Bim Adopters	Contribution
An international comparison among Australia, Singapore and China [100].	AEC industry of these three countries.	• Lack of understanding of BIM concepts and benefits • Shortage of BIM data in construction phase • Limited training and education opportunities for BIM • Resistance to change among stakeholders, including contractors, owners, and designers	A three-level strategy is proposed to address the identified barriers, which can serve as a practical reference for future research
China's prefabricated construction: An interpretive structural modeling (ISM) approach [101].	Prefabricated construction	• Limited awareness and knowledge about BIM • Limited financial resources for BIM implementation • Lack of skilled workforce with BIM expertise • Lack of standardized BIM processes and guidelines • Complex regulations and approval procedures for BIM projects	By identifying key obstacles to BIM implementation in China's prefabricated construction and developing a matching three-level approach to make it practicable, this study adds to the body of knowledge.
New Karolinska Solna Hospital, Sweden [102].	Healthcare Building	• Limited experience and skills of project team members in BIM. • High upfront costs are caused by shortage in identifying errors and jointly addressing them. • Facility managers had	The adoption of BIM was investigated in two distinct construction projects and enhanced the understanding of the barriers that impede BIM adoption.

		limited involvement during the design phase, leading to the exclusion of their expertise and insights in the project's development process. • Original design consultants may face difficulties adjusting design aspects due to differences in BIM model formats, despite BIM's single data standard facilitating a smooth transition from construction to O&M phases.	
KVMRT Line 2 (SSP Line), Malaysia [103]	Railways	• Data loss and rework due to misinterpretation • Insufficient collaboration and teamwork in the construction industry • It's crucial to manage various interests, address concerns, and ensure effective communication and engagement with stakeholders. • Every organization has its own set of BIM protocols and established workflows	The highlights include best practices, challenges, and opportunities of BIM implementation in railway construction projects, resulting in improved outcomes and performance.
Giorgini Bridge, Grosseto – Italy [104]	Bridges	• Difficulty in obtaining precise parametric elements (BOMs) for the bridge due to its complex morphology. • lack of detail recognition and occlusion. • Lack of integration of multiple survey procedures (such as TLS and SfM for UAV)	The quality of a digital model built from two independent point clouds and form images is evaluated based on two factors: its accuracy and the transformation of data into parametric elements called Building Object Models (BOMs) with

		• The model created for structural purposes was not accurate enough due to a lack of precision throughout the process. • Limited integration of diagnostic information from other sources into the H-BIM model.	unique properties..
Expeditionary Hospital Facility [105]	Healthcare Building	• Lack of efficient data transfer mechanisms from one project stage to another and internally • Shortage of familiarity with parametric concepts in the context of BIM. • quantity take-offs in collaboratively estimating costs during conceptual design.	BIM in early healthcare projects provides detailed information, optimizes opportunities, reduces costs, and enhances project management.
Large public client [106]	An organizational perspective on implementing BIM for business value	• Limited time and budget constraints were obstacles to fully engaging in BIM practices. • Some BIM pilot project managers mentioned a lack of clarity and precision in the proposed changes. • Changes to BIM pilot project's steering documents may impact industry processes.. • Project parties' lack of mutual understanding and a standardized definition of BIM poses a major obstacle to successful implementation.	Organizational challenges related to implementing BIM for business value creation were explored.

Nigerian AEC firms [107]	Developing countries	• Inaccessibility to suitable technology and framework • Low level of BIM technical know-how and awareness • Scale of culture change required. • Lack of demand by clients • Legal and contractual constraints	Ten ways are identified forward to improve BIM adoption in AEC firms, particularly in Nigeria
Haeundae L Project [108]	High-Rise Construction Projects	• Inadequate cost analysis for potential economic losses caused by poor design • Lack of quantifiable evaluation of the effects of BIM application in identifying design errors. • Rework errors cost more than design mistakes.	By estimating the various expenses related to design flaws for error prevention, BIM investment alternatives are proposed.
Raymond Barre Bridge, France [109]	Bridges	• Shortage in using open data exchange standards, specifically IFC and CityGML • Incomplete bridge model data hinders 4D scheduling and 5D cost integration.. • More IFC-bridge entity experimentation and validation needed. Explore CityGML in BIM for infrastructure projects. • Limited development and adoption of BIM for infrastructure, particularly for bridges, compared to the building domain.	A 3D bridge model is created with Revit to determine the need for defining specific entities. usage of BIM has been explored in bridge modeling with Autodesk Revit, along with an analysis of two open data transfer standards, CityGML and IFC.
Taiwan [110]	Existing Building	• Lack of effective follow-up and handling of BIM model management • Insufficient development of Standard Operating Procedures (SOPs) for BIM model management	Create a BIM execution strategy with pre-operation guidelines, describing future technological requirements and discussing sector

		• Challenges in identifying mistakes and problems that may arise during the BIM model development process • Inadequate preparation of initial BIM-related work for Facility Management (FM) during the pre-operation phase	strategy and technology requirements. Summarize constraints, difficulties, and recommendations for future BIM execution plan development.
Finland [111]	Construction engineering industry	• Lack of awareness and general demand • Small local authorities may struggle to use BIM effectively due to limited resources and expertise. • Time-consuming implementation • Software must represent BIM's structural components and cast-in reinforcements accurately. • BIM implementation may require different tools and software in different countries due to varying design standards.	Foundational research is provided to develop future tools to manage BIM technology implementations effectively.

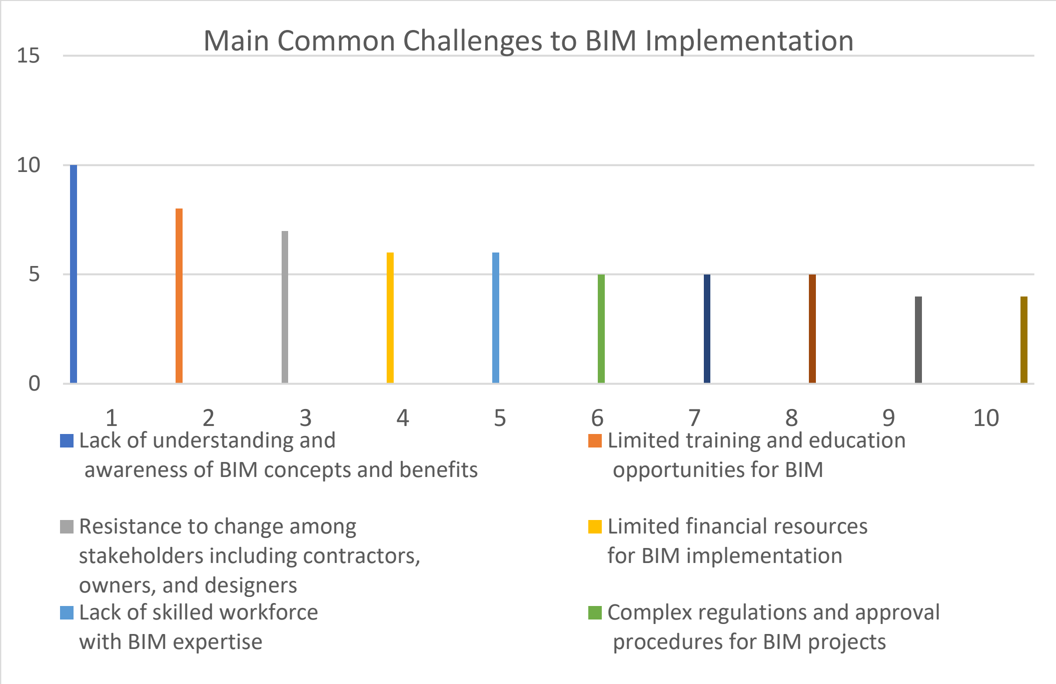

Chart 1. Main common challenges to BIM implementation according to these 12 case studies.

The chart illustrates the percentage of the main common challenges to BIM implementation. BIM implementation has emerged widely in the construction industry in recent years. The most challenging obstacle was the lack of understanding and awareness of BIM concepts and benefits as 10 of 12 addressed projects confronted this challenge. In the meantime, challenges like insufficient collaboration and teamwork in the construction industry and the legal and contractual constraints have emanated in just 4 cases of study. The Limited training and education opportunities for BIM was ubiquitous among over 60% of the projects but only 16% more than the Complex regulations and approval procedures for BIM projects challenge, the Limited experience and skills of project team members in BIM challenge and the Data loss, misinterpretation, and rework issues challenge. In addition, the resistance to change among stakeholders, including contractors, owners, and designers, is a challenge in 58% of the studied construction projects.

5. CONCLUSION

This literature review offers an extensive analysis of the implementation of BIM in transportation infrastructure projects, with a particular emphasis on integrating Industry Foundation Classes (IFC) with BIM. The study encompasses a comprehensive analysis of 12 case studies on implementing BIM in transportation infrastructure projects. Interoperability has been identified as a significant challenge, denoting the capacity of distinct software and systems to exchange information without any obstacles. The presence of data silos, inadequate workflows, and challenges in the integration of BIM with other project management and analysis tools may arise.

The review emphasizes the necessity of establishing dedicated entities and standards for the bridge domain in the IFC framework to enhance its suitability in transportation infrastructure projects. The Industry Foundation Classes (IFC) is a publicly available specification for facilitating the exchange of BIM data. However, its implementation within the realm of transportation infrastructure remains constrained. To enhance the practicality of transportation infrastructure projects, it is imperative to establish precise entities and standards. The present study investigates twelve cases of BIM integration in transportation infrastructure projects across various world regions. The research highlights popular obstacles that could limit the efficacious execution of BIM, such as the absence of standardization, inadequate knowledge and instruction, inability to change, and constraints in existing software and technology. Such obstacles may result in the delay of project completion, increased expenses, and limitations of benefits. The case studies demonstrated the advantages of BIM in transportation infrastructure projects. These benefits include better project coordination and communication, improved decision-making and visualization, decreased errors and rework, heightened sustainability, and enhanced asset management and maintenance. Research has demonstrated that BIM can enhance cooperation among various parties involved in a project, optimize project processes, and enhance project results. Utilizing effective strategies and best practices in the case studies can be instrumental in successfully implementing BIM in transportation infrastructure projects. These may include early engagement of stakeholders, appropriate training and education, standardization of data and processes, and efficient change management. The review highlights the potential impact of BIM on the transformation of the transportation infrastructure industry. Applying this strategy might increase project outcomes, sustainability, asset management and maintenance efficiency. The coordination and communication between project stakeholders can be improved by combining different transportation infrastructure project components into one integrated digital model. A comprehensive approach that addresses overcoming organizational, technical, and cultural barriers as well as encouraging collaboration and uniformity among project participants, is required for the efficient implementation of BIM.

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